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Improving Stability of Utility-Tied Wind Generators using Dynamic Voltage Restorer with Fuzzy Logic controller

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ABSTRACT

The generation of electricity using wind power is significantly increasing and has received considerable attention in recent years. One important problem with the induction generator based wind farms is that they are vulnerable to voltage disturbances and short circuit faults. Any such disturbance may cause wind farm outages. Since wind power contribution is in considerable percentage, such outages may lead to power system stability issues and also violate the grid code requirements. Thus, improving the reliability of wind farms is essential to maintain the stability of the system. The proposed strategy is to use Dynamic Voltage Restorer (DVR), which is one of the promising devices to compensate the voltage disturbance and to improve the stability of the system. It provides the wind generator with the fault ride through capability and improves the reliability of the system. Fuzzy Logic controller is used as a controller in order to control the dc link voltages and to reduce the harmonics. Simulation results for a 2 MW wind turbine are presented, especially for asymmetrical grid faults. They show the effectiveness of the DVR in comparison to the low voltage ride-through of the DFIG using a crowbar that does not allow continuous reactive power production. Extensive simulation results are included to illustrate the operation of DVR and fault compensation.

KEYWORDS: *Dynamic Voltage restore 1, Voltage Sag 2, Wind turbine 3, fuzzy logic 4*

I. Introduction

In recent years, wind power generation is in rapid expansion and its contribution to the power sector has been increasing day by day. This situation has forced the need for evaluation of their impact on power system dynamics. During short circuit fault or severe load variation, voltage sags are observed in the network. They are characterized by a sudden reduction in voltage and phase jump. The induction generators are not able to withstand such low voltages due to reactive power needed to restore the internal magnetic flux, once the fault is cleared (Milanovic, 2007). Figure1 shows the variation of the voltage and reactive power absorbed by the induction generator with slip. It can be seen from the figure that as the slip or the power increases, the amount of reactive power absorbed by the generator also increases. Due to the large amount of reactive power drawn from the network, the voltage across the transmission line drops. The voltage at the point of connection with the network decreases, as the slip increases. The voltage recovery after disturbance is hindered by the consumption of reactive power. This behavior limits the fault ride through capability. Hence, wind farms are disconnected during fault for safety. In the past, the wind power penetration was low in percentage and hence, any outage might have not affected the system stability. But now these days, wind generation is in rapid expansion and its contribution to the grid is as conventional generation plants as stated by Bollen (2005). Hence, any outage of wind plant may lead to power swing and collapse the stability.

In this paper, the issues related to stability of Fixed Speed Induction Generators (FSIG) based wind farms are analysed. The wind farms are operated in two modes, one as grid integrated mode and the other as standalone mode. When a wind system is inactive, the grid supplies electricity to the consumers. When surplus electricity is produced by wind farms, it meets the local demand and the remaining power is fed to the grid. The utility

employs a billing system known as net metering. Net metering is a system in which the electric bill is based on net consumption minus production. The electric billing is based on the amount of utility energy consumed minus the amount of energy provided to the grid from a renewable energy system. A safety disconnect switch is available near the point of connection, which enables service personnel to disconnect wind farms from the grid during fault condition and to be operated as a standalone system. Hence, a wind farm serves consumers as stand-alone mode. In both modes, the wind generator suffers with stability problems by grid faults or load disturbances. Hence, the distributed generation system focuses on power quality improvement (Singh, 2011). Several schemes are under research for protection and power quality improvement (Siozinys, 2012; Vaimann, 2012). Grid tied active filters are usually designed for performance improvement (Biricik, 2013). The proposed strategy is to use dynamic voltage restorer DVR for voltage sag compensation by series voltage injection as shown in Figure 2. DVR is a power electronic controller that can protect the wind farm from disturbances without loss of stability and guarantee the reliability of the system. The proposed DVR can also limit the fault current and protect the DG from over current due to voltage disturbance.

II. Configuration of DVR Circuit

Block diagram of DVR with Wind Energy System shows in the fig.1. It consists of 3-leg IGBT based inverter and DC sources. The supply is 11kV fed form distribution system. Then 11kV is step-down to 415 V by star to star connected transformer. In paper polluted distributed system is consider as a system which consists faults, non- linearity and unbalanced in voltages. For that two different types of load are consider as uncontrolled.

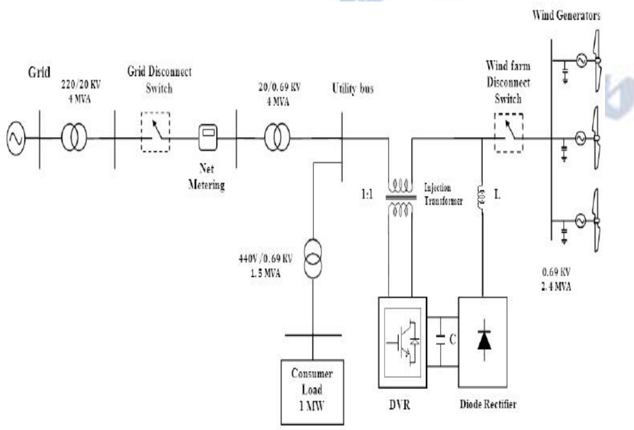

Fig.1 Block diagram of DVR with Wind Energy System

III. DYNAMIC VOLTAGE RESTORER AND ITS OPERATING PRINCIPLE

A. Dynamic voltage Restorer:

Dynamic voltage is one of the custom power device which is used for voltage sag/swell elimination and it consists of a VSC (Voltage Source Converter), storing device (Battery), Passive Filters, Injection transformer also known as Coupling transformer, In DVR VSC is made up with 6 IGBT switch which is used for conversion of dc link voltage into ac supply and there a battery which acts as dc link voltage and as well as storing agent and there placed a passive which is elimination of switching harmonics, when voltage source converter converts ac-dc or dc-ac we get ripple in the output supply of VSC and in order to eliminate those ripples passive filters are used and this output of the ripple filter is connected to the injection transformer and which injects the filtered supply into the bus or feeder. When there is no disturbance in the system the injected transformer will be short circuited by the switch to decrease losses and increase cost effectiveness. The o/p of the DVR is completely depending upon the PWM technique and control method. The PWM generates signal by comparing sinusoidal signal with the carrier wave signal and sending appropriate signal to the Inverter.

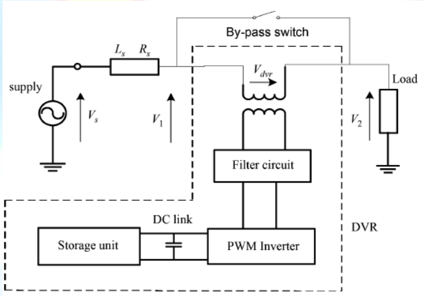

Fig.2 Schematic Circuit of Dynamic Voltage Restorer

B. Working principle of DVR:

When voltage drop occurred at load, DVR will inject a series Voltage through transformer so that the load voltage can be maintained at nominal value. By using injecting transformer DVR supports loads voltage when the voltage drop occurs due to faults.Fig.3 Shows Equivalent circuit for DVR.

$$V_{DVR} = V_L + Z_{th} I_L - V_{th} \quad (1)$$

$$I_L = \frac{P_L + jQ_L}{V_L} \quad (2)$$

For analysis VL is as references

$$V_{DVR} \angle \alpha = V_L \angle 0^0 + Z_{Th} I_L \angle (\beta - \theta) - V_{th} \angle \delta \quad (3)$$

Here VDVR, Zth and Vth angles are consider as α, β and δ. power factor angle is consider as θ

$$\theta = \tan^{-1}\left(\frac{Q_L}{P_L}\right) \qquad (4)$$

Thus, DVR injected power is consider as

$$S_{DVR} = V_{DVR} \qquad (5)$$

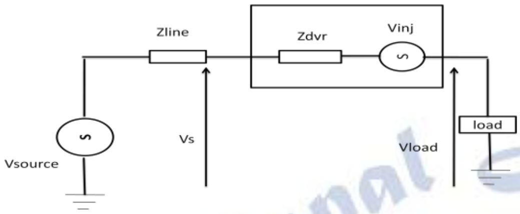

Figure 3: Equivalent circuit diagram of DVR

3.2 DVR Control Techniques

In paper, PI controller and FLC two types of control strategies are used to mitigate sag.

3.2.1 Proportional-Integral (PI) controller

The main aim of the PI controller is to keep constant voltage at load during any unwanted disturbances occurs in the supply voltage. Comparing load voltage with references voltage as consider as controlling method here. First all three phase voltages are converted in to p.u values then converted into dq with help of park transformation. After that compare the d- voltage value with 1 and q- voltage value with 0 because as per IEEE stands rated voltage p.u d-component must be as well as q component must be 0. After comparing the original value with reference value the difference is given to the PI controller for enhances. The given signal by PI controller is convert into abc components by using clerk transformation because for generate switching signals to invert this signal is basic. Fig 4 shows the conventional PI controller. The major role of PI controller is to find voltage sag, supplies voltage deviations and on/off invert while voltage disturbances event.

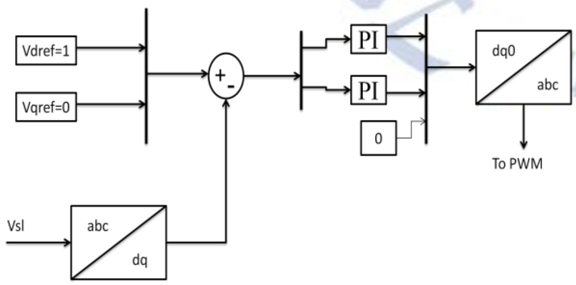

Figure 4: PI controller

3.2.2 Fuzzy Logic controller (FLC)

Fig.4 shows Fuzzy logic controller which is used in place of PI controller to overcome the problem in that. Form the fig.4 in this two fuzzy controllers is used one is for d-voltage error component and other one is for q- voltage error component. In this analysis two inputs are consider for one is error and error rate and 7 linguistic variables for each input and 7 linguistic variables for output is consider. Triangular membership functions consider for voltage error, error rate and output variables. A 49 rules used to track output values in fuzzy logic controller. Fuzzy logic is designed in the mandani's method and a centroid method is used for the defuzzification.

In this paper for first fuzzy logic one of the input is consider as error in voltage d-component (Vd) and other input is consider as error rate (ΔVd) , second fuzzy logic one of the input is consider as error in voltage q-component (Vq) and other input is consider as error rate (ΔVq). In this paper, error and error rate are designed by linguistic variables such as negative medium (NM).Negative big (NB), negative small (NS), positive small (PS), positive big (PB), Zero (ZE), positive medium (PM).the output alssp design by 7 variables negative medium (NM).Negative big (NB), negative small (NS), positive small (PS), positive big (PB), Zero (ZE), positive medium (PM). The membership functions of inputs and output show in figure 6, 7, and 8 receptively. Fuzzy rules are show in table 1.

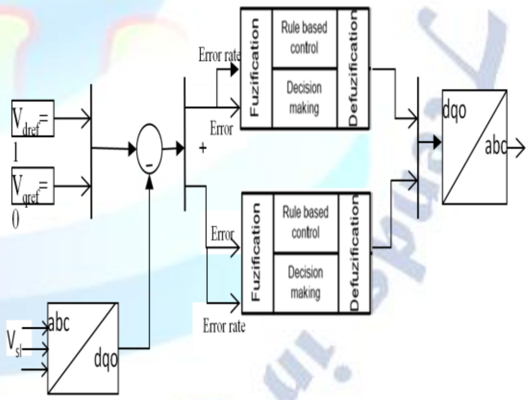

Figure 5: Fuzzy Logic Controller

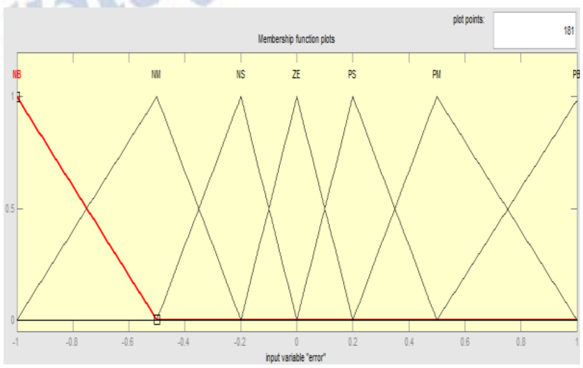

Figure 6: Error (input1) member ship functions

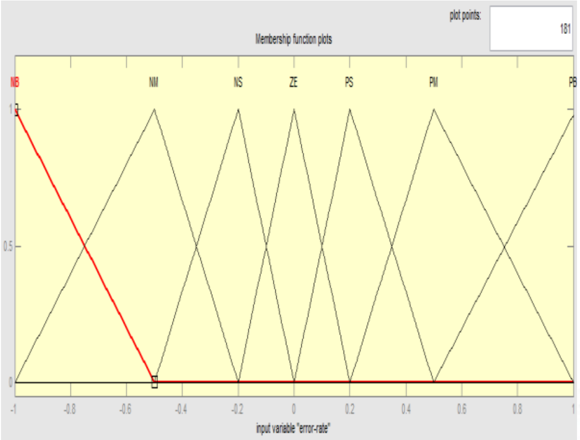

Figure 7: Error rate (input2) member ship functions

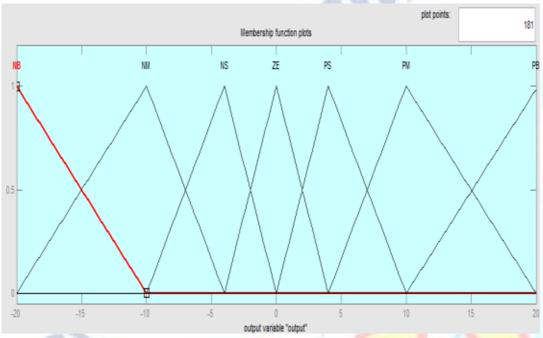

Figure8: Output membership functions

Table 1: Fuzzy rules for Fuzzy controller

Ce\e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PM	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PM	PB	PB	PB

4. Simulation results and discussion

4.1 Grid connected FSIG

Case 1

A Symmetrical Grid fault and its impact on FSIG are analysed. A voltage dip of 100%, due to a symmetrical fault, is created for 200ms as shown in Figure 6(a). The sequence components are shown in Figure. 6(b). It is found that during a symmetrical fault, only the positive sequence components are present whereas the negative sequences are found only at the beginning and the ending of dip. Figure.6(c) shows the current over shoot during voltage dip. This enormous current may damage the FSIG wind turbine and even transient failures may be encountered. Hence, usually the wind generators will be disconnected and isolated from the network for safety. But, this scenario leads to a stability problem. The sag mitigation is the only solution to avoid the aforementioned problem and to make the generator stay connected with the system. With the aid of DVR, a dip caused by fault is compensated and hence, normal operation is unaffected. Voltage sag magnitude is calculated and DVR reference voltage is generated for compensation. The DVR compensation voltage is depicted in Figure 9(a). The sag is compensated by an in-phase insertion of voltage in series with the line. Figures 9(b) and Fig. 9(c) show the compensated voltage and current at the wind generator using the vector controller.

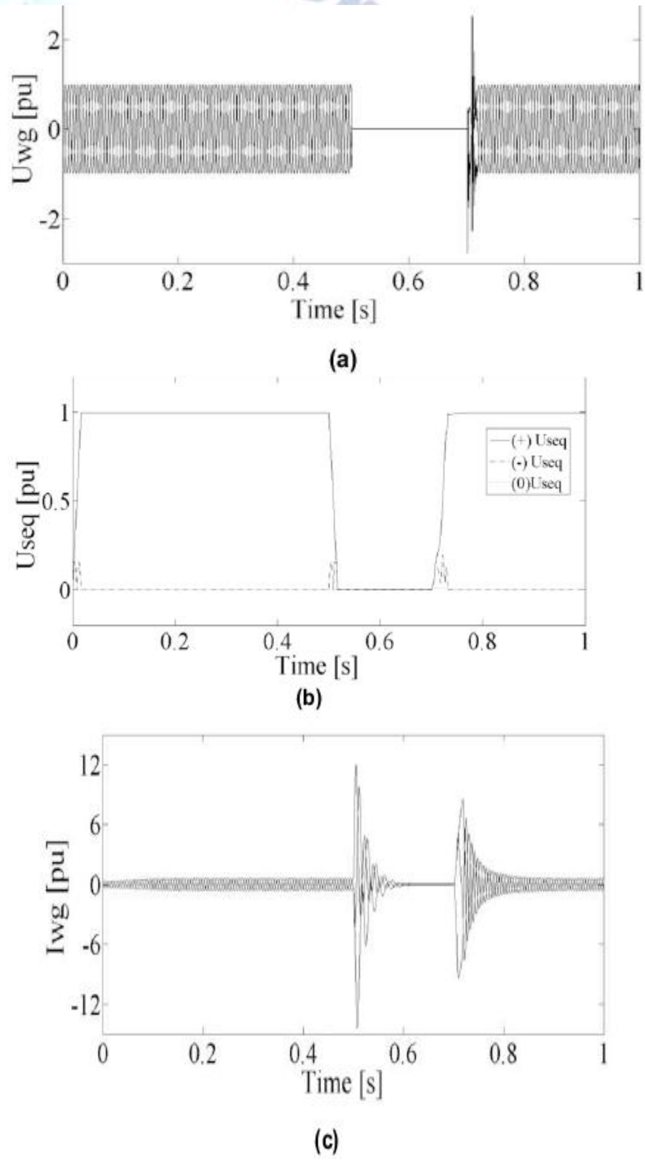

Fig 9: (a) Wind generator voltage during 100% dip before compensation (b) sequence components during dip (c) current overshoot during dip

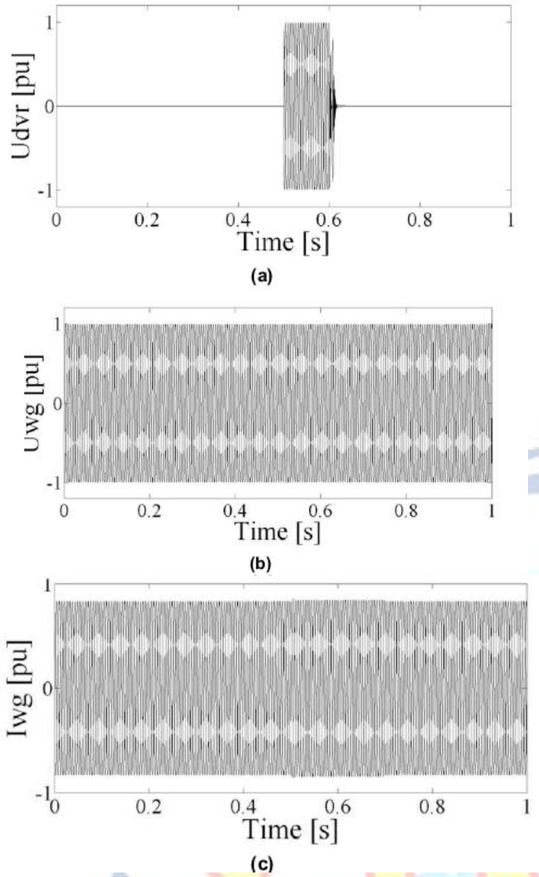

Fig10. (a) Compensation voltage of DVR (b) Wind generator voltage after compensation (c) Wind generator current after compensation

4.3 Total Harmonic Distortion

For this case faults aren't consider only a non linear load is connected in parallel to the sensitive load. Due nonlinearity of nonlinear load will creates distances in voltage of sensitive load in that causes DVR will injects missing voltages in the system to maintain the load voltage constant. Fig 14 injects voltages of DVR with Non linear load.

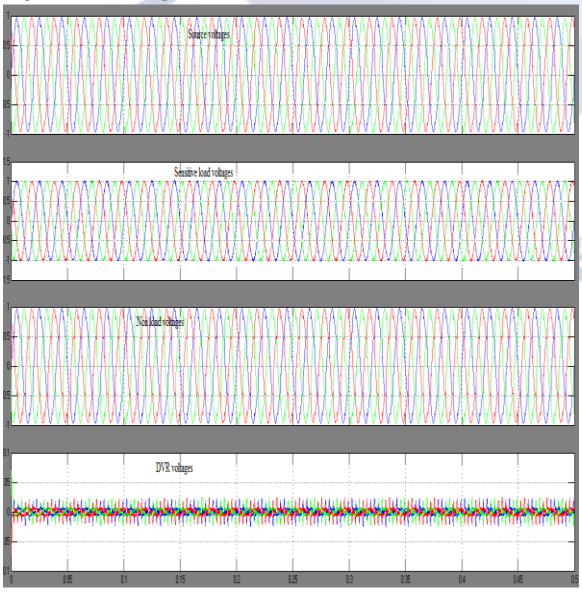

Figure 11: DVR performance with Non linear load

Form the above results DVR is mitigated voltage sag at different magnitudes for different faults with PI and Fuzzy controller very perfectly. Using the Fast Fourier Transform (FFT) analysis to analyze the Total harmonic distortion (THD) for the signal of load voltage is anglicized. Before mitigation of Voltage sag (three phase to ground fault) 6.91% THD in load voltages. PI controlled DVR having 1.56% of THD in the sensitive load voltages. Fuzzy logic controller DVR having 1.44 % of THD in the sensitive load voltages. Fig. 15.16 and 17 shows the FFT analysis and THD values of Without DVR, With DVR PI controller, With DVR with Fuzzy controller.

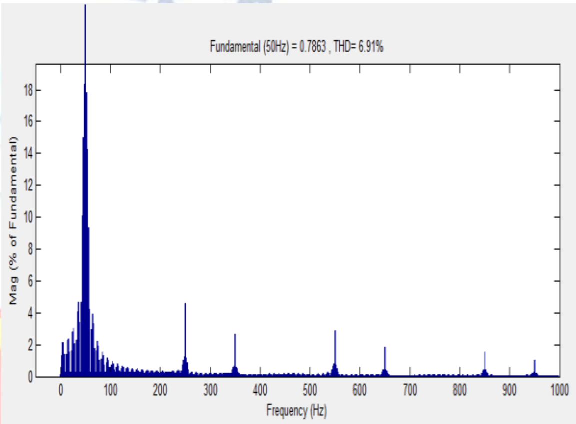

Figure 12: FFT analysis of Load Voltages with Three phase to ground fault and nonlinear load (without DVR)

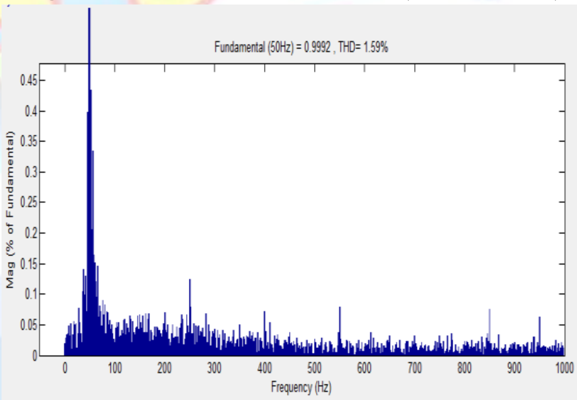

Figure 13: FFT analysis of Load Voltages with Three phase to ground fault and nonlinear load (with DVR with PI controller)

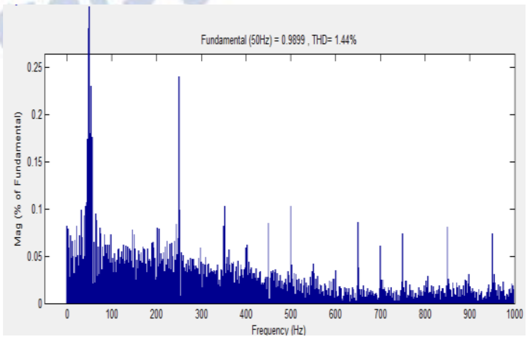

Figure 14: FFT analysis of Load Voltages with Three phase to ground fault and nonlinear load (with DVR with FLC controller)

Form the above results DVR is mitigated voltage sag at different magnitudes for different faults with PI and Fuzzy controller very perfectly. Using the Fast Fourier Transform (FFT) analysis to analyze the Total harmonic distortion (THD) for the signal of wind generation voltage is anglicized. Before mitigation of Voltage sag (three phase to ground fault) 6.91% THD in load voltages. PI controlled DVR having 1.56% of THD in the sensitive load voltages. Fuzzy logic controller DVR having 1.44 % of THD in the sensitive load voltages. Fig. 15.16 and 17 shows the FFT analysis and THD values of Without DVR, With DVR PI controller, With DVR with Fuzzy controller.

5. Conclusions

The fault ride through capability of the induction generator based wind farm is improved with the aid of a DVR. The wind generator remains connected to the grid without loss of stability and guarantees the reliability of the system. The proposed DVR can mitigate voltage disturbance and provide reactive power support. It is also a suitable scheme for standalone operation. The developed models of Wind farm and DVR control strategies demonstrated the viability of the proposed scheme. The results show that the control technique is very effective and yield excellent compensation for voltage disturbance and associated problems.

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